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Fiber Reinforced Composite Pipelines

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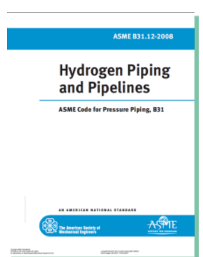

Project ID #: PD022

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Overview

Timeline

- Project start date:10/2006
- Project end date:10/2017*

* The completion of this project is at the discretion of DOE based on program needs

Barriers

- High Capital Cost and Hydrogen Embrittlement of Pipelines ($490K/mile Transmission and $190K/mile Distribution Costs
- Safety, Codes and Standards, Permitting

Budget

- Funding for FY13
  - FRP Pipeline $200K
  - Additional $100K to be received

Partners

- Commercial FRP Manufacturers
- ASME
- ORNL

Relevance – 2010 DOE Technical Targets

“Develop hydrogen fuel delivery technologies that enable the introduction and long long-term viability of hydrogen as an energy carrier for transportation and stationary power”

-*DOE Hydrogen Delivery Goal*

DOE Barriers	SRNL Goal
High Capital Cost and Hydrogen Embrittlement of Pipelines	Provide test data to support a technical basis to support fiber reinforced piping in hydrogen service. The specific details for implementation of FRP in Hydrogen service are addressed in an FRP Life Management Plan that SRNL developed in collaboration with ASME.
Safety, Codes and Standards, Permitting	Have FRP integrated into the ASME B31.12 Hydrogen Piping and Pipeline Code by 2015. The proposed SRNL Demonstration will facilitate codification, public acceptance and provide a test case for permitting.

Relevance – FRP for H_2 Delivery

- **Impact:**
  - Composite pipeline technology has the potential to reduce installation costs and improve reliability for hydrogen pipelines
- **Advantages to using FRP**:
  - Excellent burst pressure ratings
  - Superior chemical and corrosion resistance
  - Long lengths can be spooled for delivery reducing installation cost
- **Existing Technology:**
  - FRP is an existing commercial technology currently employed in the oil & gas business—commercial product up to 6” diameter and 2500psig pressure rating

SRNL FRP Accomplishments (Prior Years)

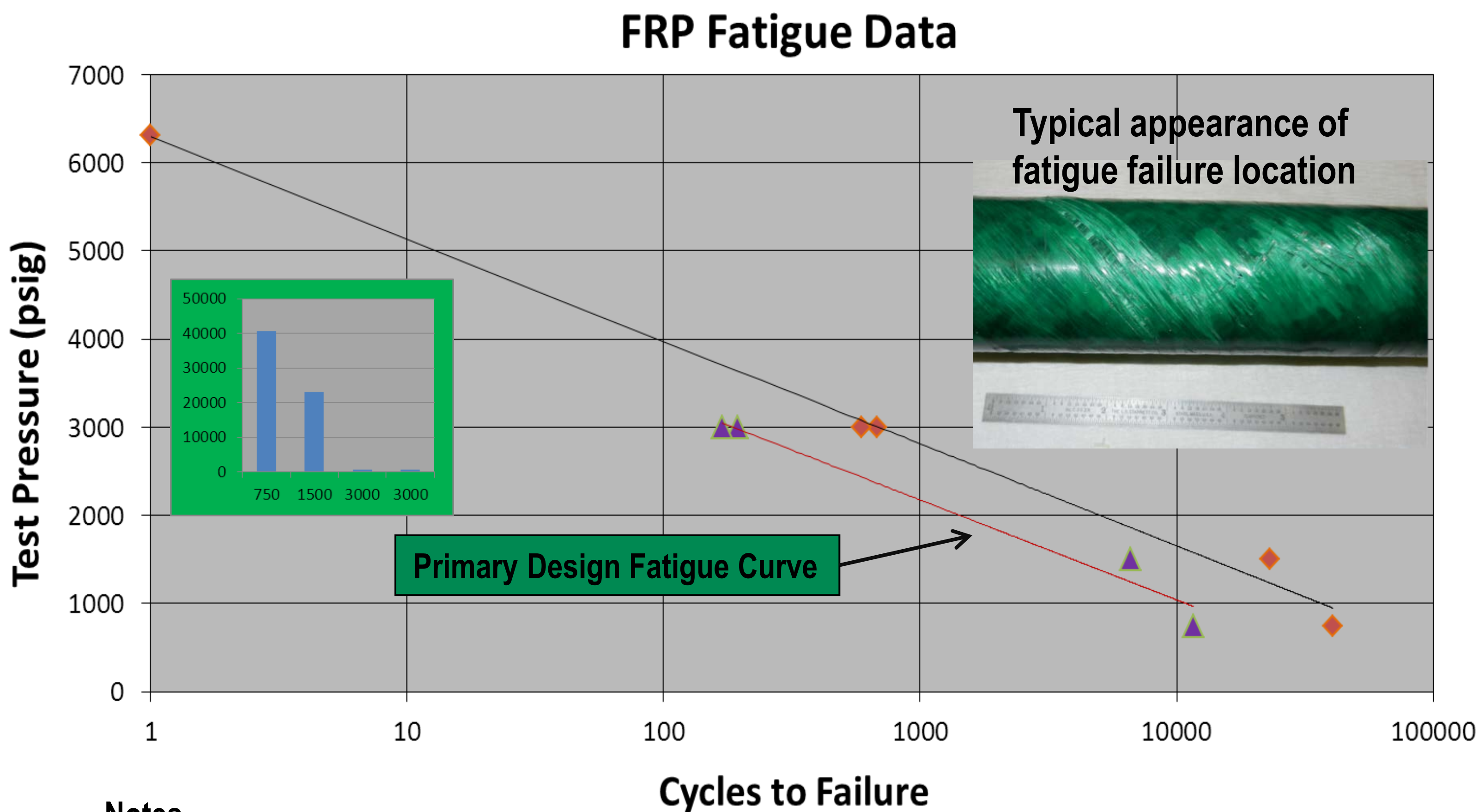
- **SRNL in collaboration with ASME has developed an FRP Life Management Plan. The plan recommended investigation is needed in the following areas:**
  - System Design and Applicable Codes and Standards
    - Complete review of relevant FRP piping and pressure vessel standards
    - Burst test of piping to evaluate design margins
  - Service Degradation of FRP
    - Tested FRP following high and low PH exposure
    - Evaluated joint I for leak integrity
  - Flaw Tolerance and Flaw Detection
    - Evaluated effect of flaws on burst strength to support design margin
    - Evaluated effect of flaws on fatigue life. Will support installation inspections

SRNL FRP FY 2013 Accomplishments

Fatigue Testing

- Fatigue testing of FRP was started at SRNL during FY 2012 and is continuing during FY 2013. The fatigue testing is directly linked to the FRP Life Management Plan.
- **1500 PSI Fatigue Test -**The first test was performed at the rated pressure of the FRP product of 1500 psi. During the test a seal failure of the mechanical connection was observed at 14424 cycles. The O-ring seals were replaced and the test continued. The 1500 psi test sample has been cycled to 20,127 cycles where a structural failure of the pressure boundary occurred.
- **3000 PSI Fatigue Test –** Two fatigue test was performed at 3000 psi which is twice the product rated pressure. During the first 3000 psi test seal failures occurred at 447 cycles followed by a structural failure of the pressure boundary at 593 cycles. A second 3000 psi fatigue test failed in the pressure boundary at 681 cycles. Inspection showed damage to the O-ring at completion of the second 3000 psi fatigue test , but no seal failure occurred.
- **750 PSI Fatigue Test -** A fatigue test was performed at 750 psi which is half the products rated pressure. The test sample has been cycled to 40,000 cycles without a structural failure where the test was terminated. A seal failure damage was observed at 23,071 cycles. The O-rings were replaced and the test was completed. The damage was less severe then in the 1500 and 3000 psi tests.

Fiber Reinforced Composite Pipeline- Fatigue Testing



Notes

1 Single cycle test represents burst test data

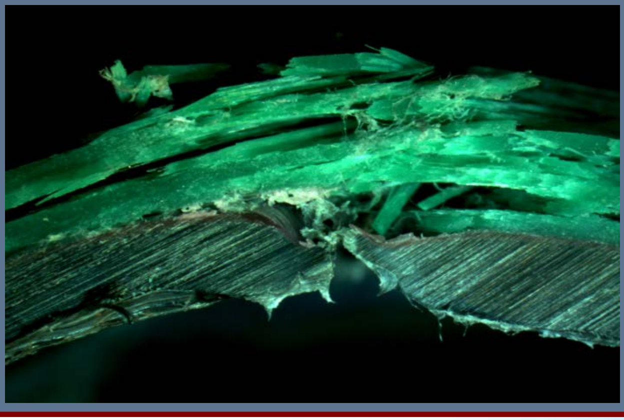
2 750 psig fatigue test was terminated at 40,700 cycles without a structural failure

Fiber Reinforced Composite Pipeline- Fatigue Testing

Section Cut From Fatigue Sample

- A 3000 psig test specimen was sectioned and photographed. The internal view shows an approximately 3 inch long crack
- The magnified view through the cross-section show delamination and fiber breakage

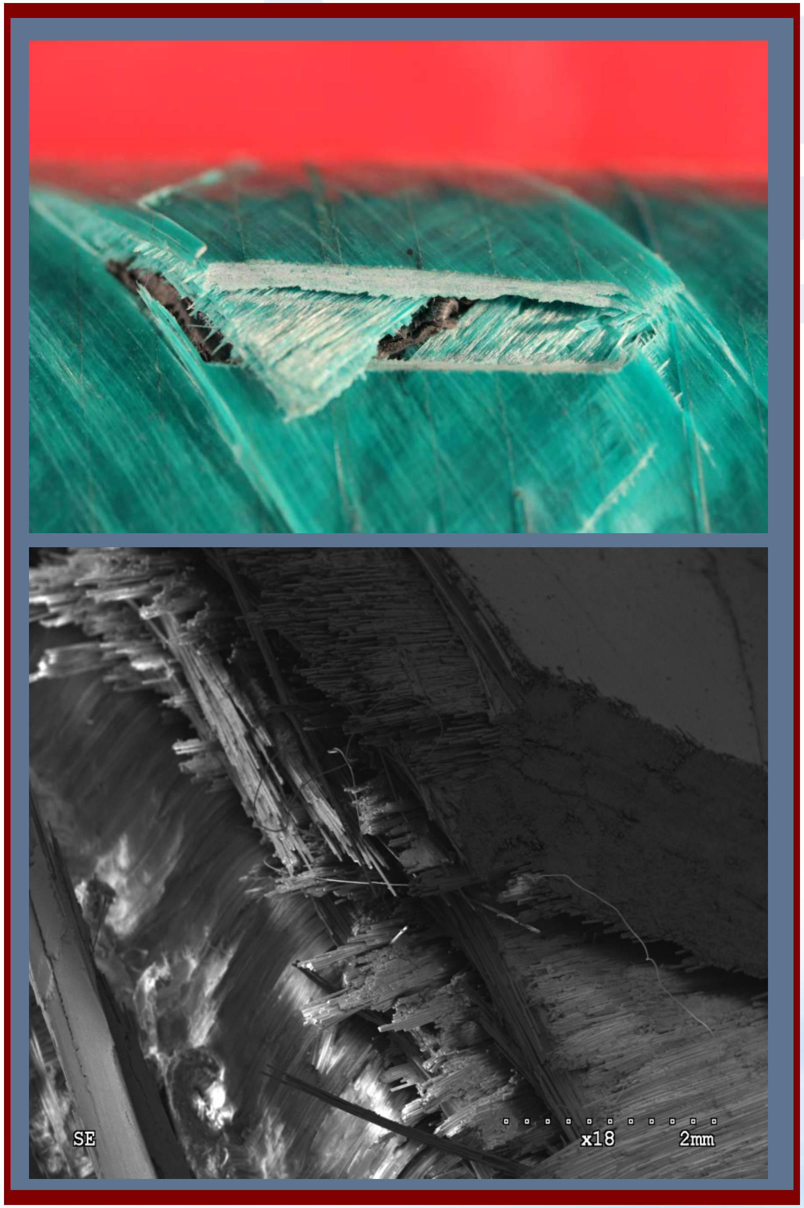
Inside View Showing Rupture of Liner



Cross-Section View Through Crack

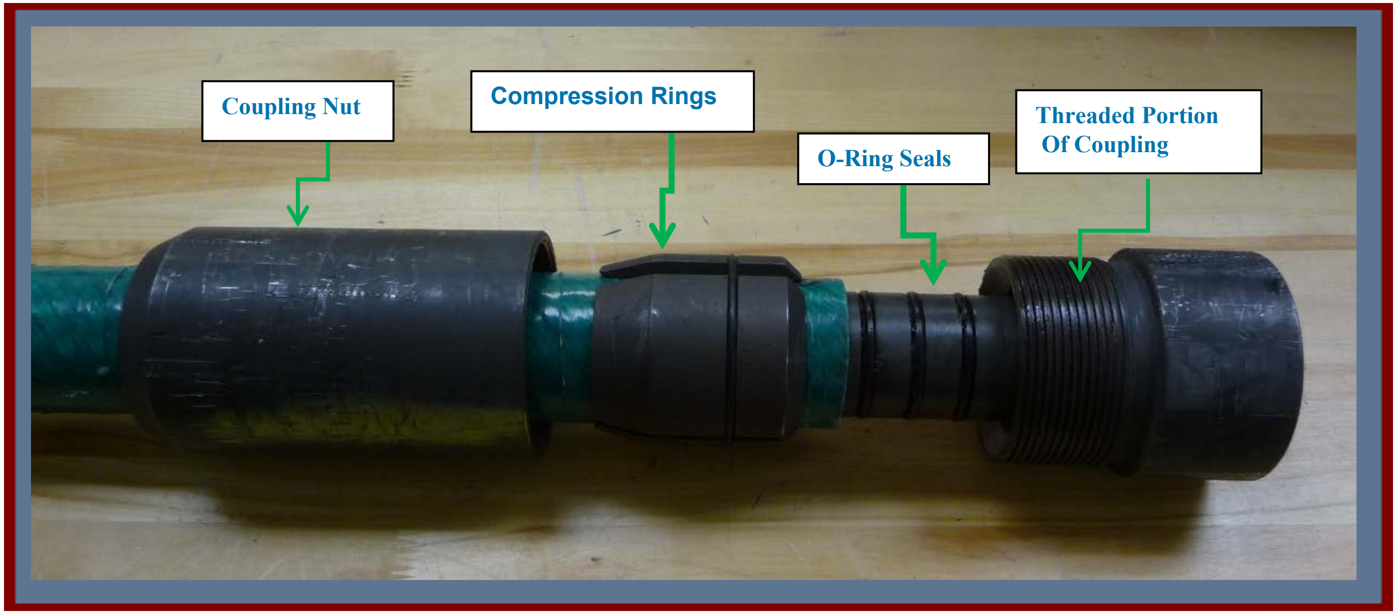
Fiber Reinforced Composite Pipeline- Fatigue Testing

- Fatigue Tests have been performed on 2 flawed FRP samples (These test were completed in FY 12)
- The baseline flaw (1” x 0.125”) a 40 % depth was tested.
- The 2 flawed samples failed after 2830 and 4862 full design pressure cycles
- The failure mode showed that the delamination of the FRP stated to occurred at the bottom of the flaw and continued through thickness until failure occurred
- This data will be used to provide design and inspection information for ASME Codification



Fiber Reinforced Composite Pipeline- Fatigue Testing

FRP Connectors -The connectors are all metallic with elastomer O-ring seals. To form the connection the internal diameter of the polyethylene liner is machined to a specified diameter. The machined portion of the liner is where the O-rings in the metallic connector interface with the composite piping to form the fluid seal. The outer nut of the connector is tightened, mechanically compressing ferrules on the piping, resulting in compression of the seals



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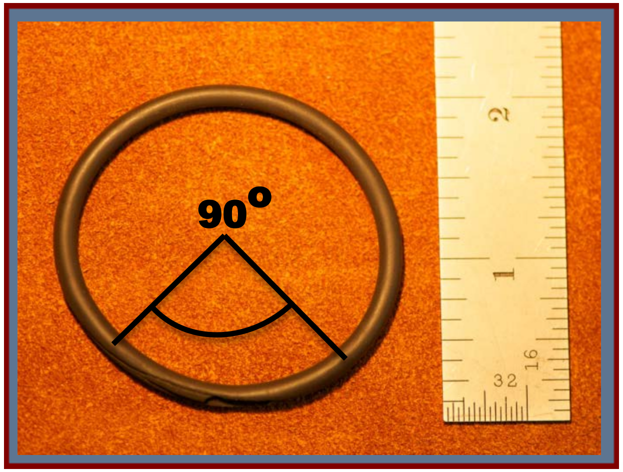
Fiber Reinforced Composite Pipeline- Fatigue Testing

- O-ring failures occurred during the fatigue testing of the structural layer at all pressure levels
- The O-ring failures show classic indication of extrusion from their retaining grove
- The failure is a progressive distortion of the O-ring from the fatigue loading. The O-rings did not leak while testing with hydrogen or during burst testing

O-ring Damage 750 psig Fatigue Test



O-Ring Damage 3000 psig Fatigue Test

Fiber Reinforced Composite Pipeline- Fatigue Testing

• Resolution of O-ring Failures

- The failure is a progressive distortion of the O-ring from the fatigue loading
- Testing of the O- ring material showed that the material hardness (durometer level) was lower than the specified design value. Tested values showed that the rubber hardness was in approximately 60 Durometer M. Where values of 70 to 90 would be required based on literature data

Micro-O-Ring Hardness

- The use of a back up ring to limit the deformation of the O-ring is another common solution.
- This data will be used to provide design and inspection information for ASME Codification

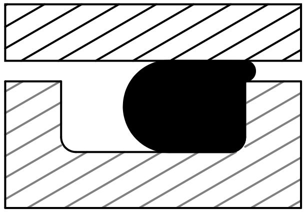
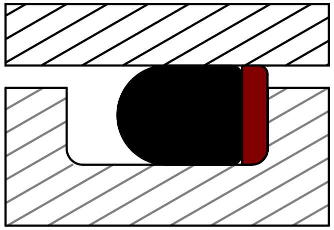
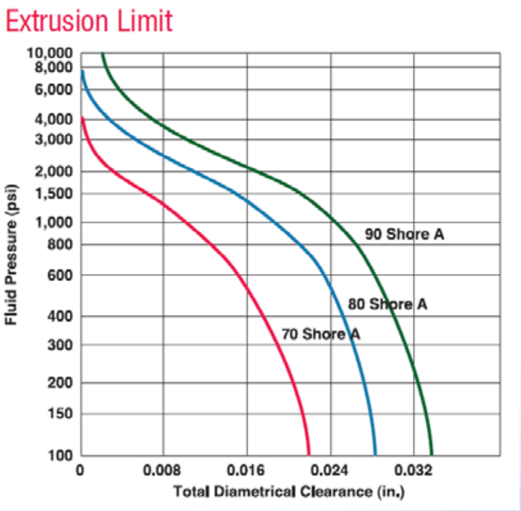


Illustration of O-Ring Extrusion



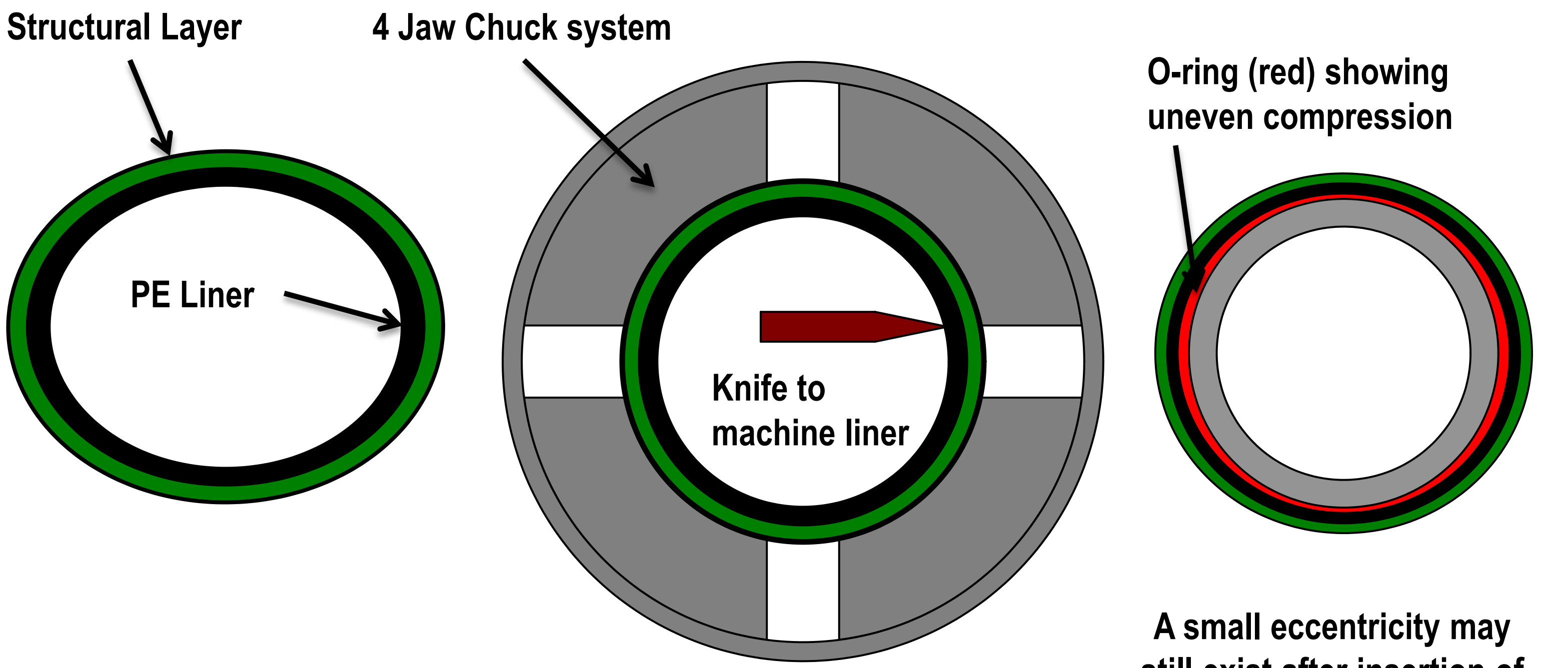
O-Ring Gland with Backing Ring



From Apple Rubber Company

Fiber Reinforced Composite Pipeline- Fatigue Testing

Illustration of Variation in O-Ring Compression



FRP Cross-Section Initially has a slight oval shape

A 4 jaw chuck system is used bring FRP concentric where liner is machined to coupling diameter

A small eccentricity may still exist after insertion of coupling resulting in uneven O-ring compression and partial extrusion

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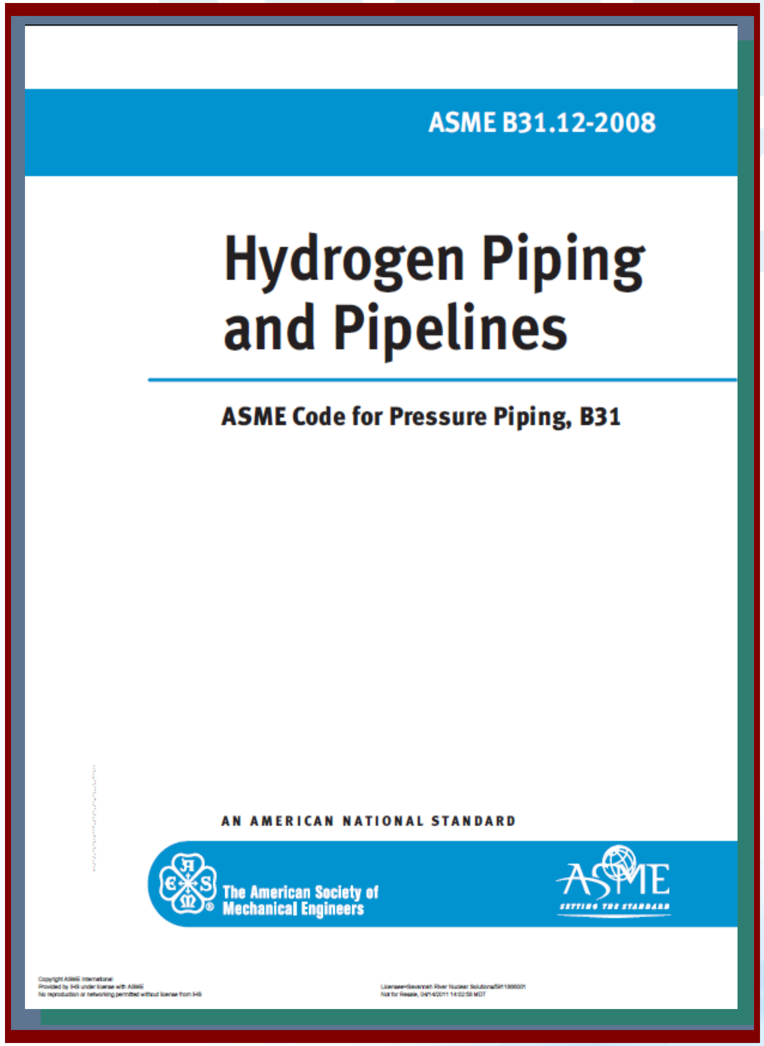
SRNL FRP FY 2013 Accomplishments

- **FRP in Moist Environments**

    - The resistance of a composite for use in a water environment is dependent on the matrix resins ability to slow the migration rate of water into the composite
    - Industry has used and Interlaminar Shear Strength test be performed following boiling the test sample in water for 24 hours to shoe adequacy for composite use in moist environments
    - ASME adopted the use of the interlaminar shear strengtht o ASTM D 2344 "*Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*" for high pressure composite vessels
    - Industrial experience was available from a Fiberspar pipe section. Following 12 years of service in Alberta, Canada a piping sample was evaluated and shown to meet the factory acceptable minimum values for burst pressure and glass transition temperature for a new pipe

SRNL FRP FY 2013 Accomplishments

- **B31.12 Codification**
- A report summarizing the FRP testing by SRNL and ORNL has been completed. The report will become the basis for ASME Codification of FRP
- Review comments from ASME, ORNL and Fiberspar have been incorporated.
- The reported will be updated to include the 2013 fatigue testing data and the service experience data from Fiberspar
- The revised report will be provided to the B31.12 Code Committee for Peer Review in June 2013


ASME B31.12-2008

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

ASME
SETTING THE STANDARD

Fiber Reinforced Composite Pipeline - B31.12 Codification

- **The FRP codification report was co-authored by SRNL and ORNL and addresses the following topics**

  - ASME Methodology
  - Materials
  - Product Form
  - Product Form Testing
  - Glass Fiber Testing
  - Literature Review of Potential Degradation of Polymers in Hydrogen
  - Permeation Leakage through the Polymer Liner
  - Control of Material for Codification
  - Piping Industry Design Margin Methodology
  - Glass Fiber Stress Rupture Data
  - ASME Experience with Composite Vessels in Hydrogen Service
  - Control of Design Margins
  - FRP Flaw Tolerance
  - Environmental Testing
  - Fatigue Testing
  - Evaluation of Piping Joints
  - Extended Design Life for FRP
  - Fabrication Requirements
  - Examination Requirements
  - Testing Requirements

Summary

- FRP is an attractive technology with potential to support the DOE goal to reduce overall pipeline installation cost
- Fatigue testing over the range of 750 psig to 3000 psig has been completed. The data provides an initial indication on the fatigue life of FRP. The variability in the data still need additional investigation. A preliminary design fatigue curve has been proposed based the current test data with a design margin applied based on literature review to estimate the variability
- Fatigue testing of both flaw been conducted. These tests have shown that a flaw will effect the fatigue life of FRP. These flawed fatigue test provide valuable information for installation and inspection requirements
- The O-ring failures are a not structural failure of the pressure boundary, but still provide valuable data for the FRP codification process. The results of the O-ring failure analysis will be applied to specify attributes of the connector for examination, and types of examinations that need to be performed during fabrication and installation of the mechanical joint for the FRP pipeline
- A report summarizing the FRP testing by SRNL and ORNL has been completed. The report will become the basis for ASME Codification of FRP. Review comments from ASME, ORNL and Fiberspar have been incorporated

Proposed Future Work – SRNL Scope for FRP

- Perform additional fatigue testing in collaboration with Fiberspar to determine the variability in the fatigue data
- Collect and document available service history data for FRP from literature and FRP manufacturers
- Perform a long term stress rupture test for flawed FRP samples
- Evaluate non-mechanical joints for FRP application
- Development inspection criteria for FRP joint based on conclusion from O-ring fatigue failures
- Complete FRP Codification into ASME B31.12

Technical Back-Up Slides

FRP Life Management - Burst Testing

Evaluation of Third Party Damage

Multi - Layer Reinforcement

Baseline Flaw

Width 1"x 0.125"

40% Depth

- Reduction in Burst Pressure from unflawed condition to 40% through wall flaw of 28 % for short term burst and multiple layer reinforcement
- With the 40 % through wall flaw there is still a margin of approximately 3 above the rated pressure

Failure mode changes from global to local and then move back towards global as flaw depth increases

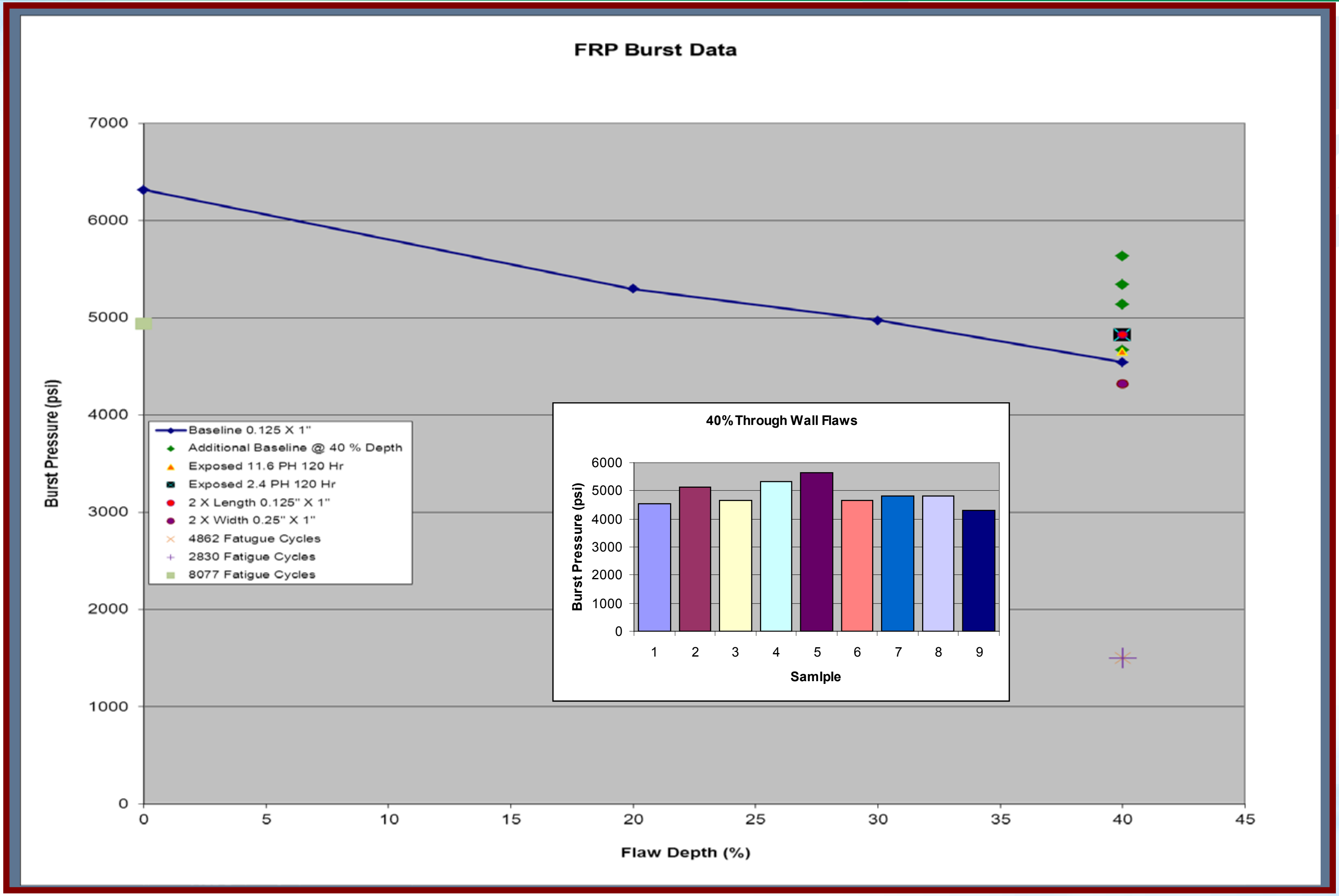
2 X Width 1"x 0.25"

40% Depth

2 X Length 2"x 0.125"

40% Depth

Fiber Reinforced Composite Pipeline Test Data



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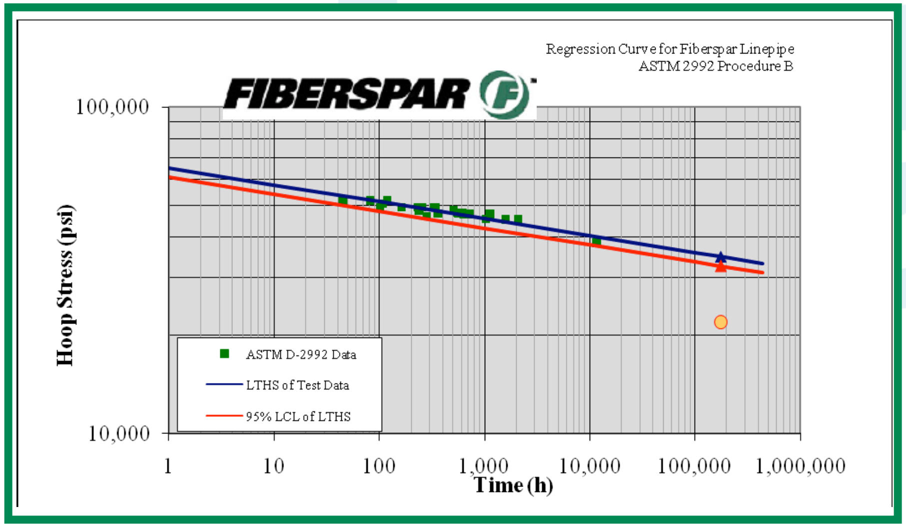
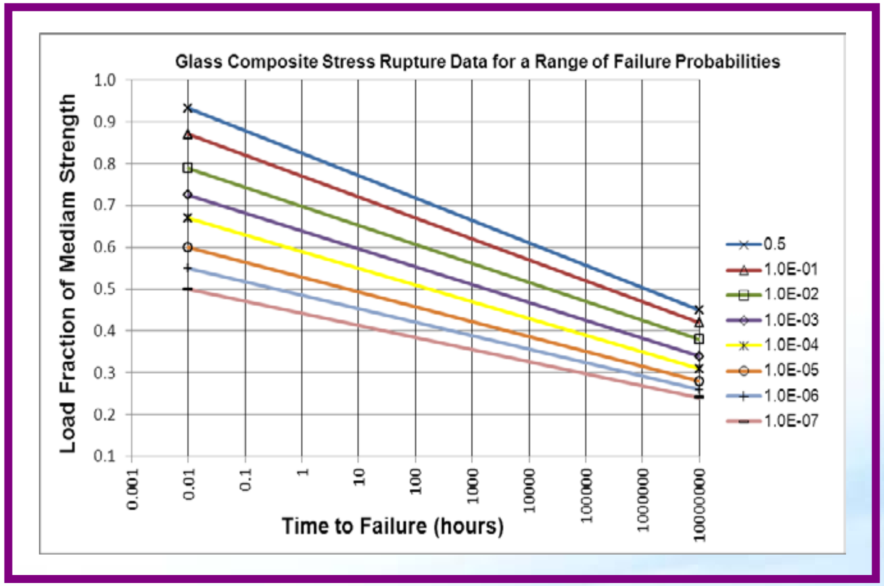
Design Margin for FRP

- Stress ratios are being set in newer standards to address reliability in regards to stress rupture as compared with the Hydrostatic Design Basis used in ASTM D2992

- The date provided by Robinson, Aerospace Corporation has shown that a margin of 3.5 on the burst pressure (.28 Stress Ratio) will provide a creep rupture life of 25 years

- Burst data for FRP Design to ASTM D2992 indicated that the margin on burst of 4.0 indicating that there is additional margin to address factors like third party damage, increased design life and environmental conditions





Robinson, Aerospace Corporation

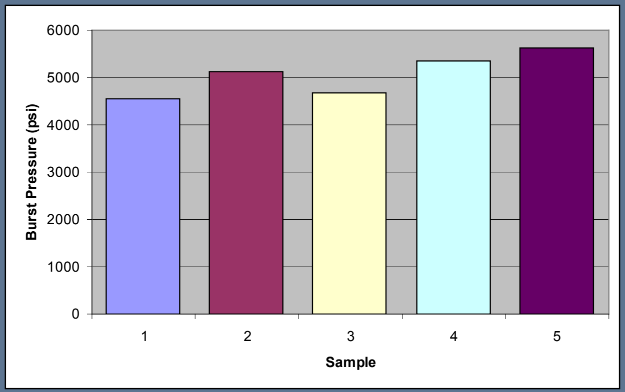
Fiber Reinforced Composite Pipeline

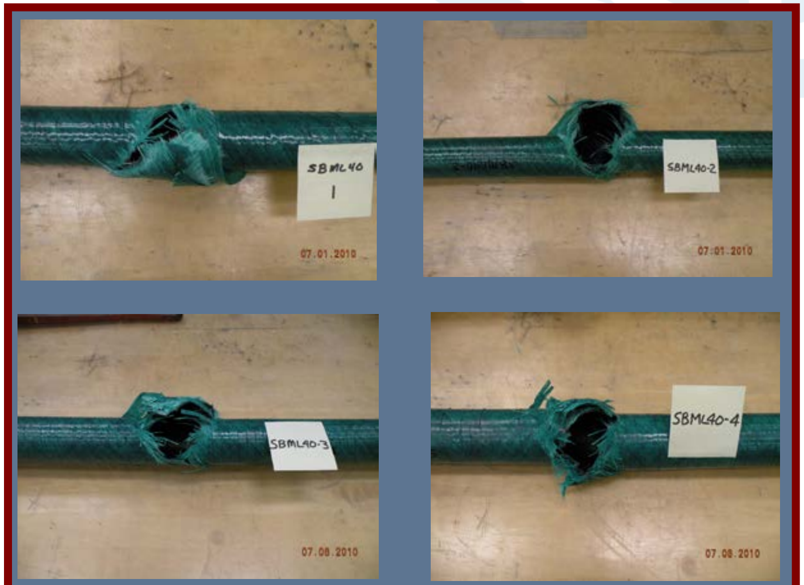
Evaluation of Third Party Damage Multi - Layer Reinforcement

Additional Baseline Flaw

1”x 0.125”

40% Depth



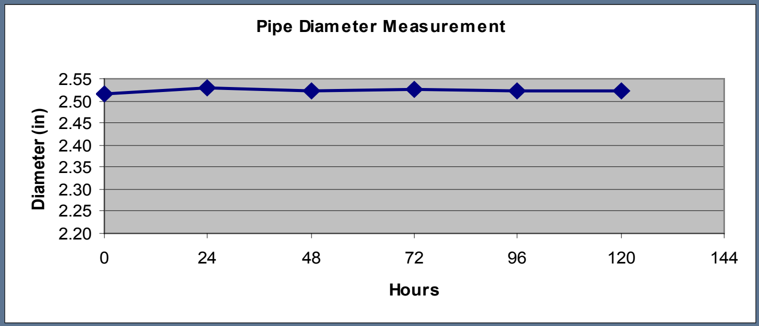


Baseline Flaw

1”x 0.125”

40% Depth

No Evidence of Bulging Under Sustained Pressure



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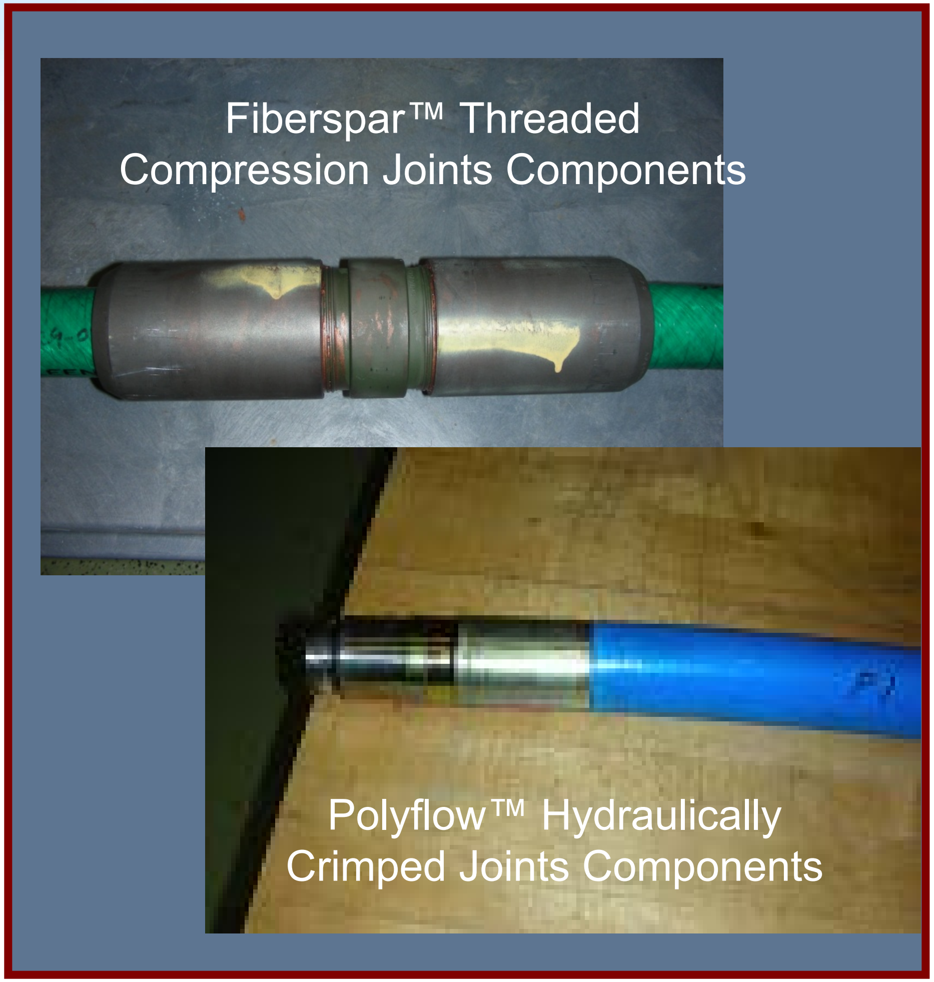
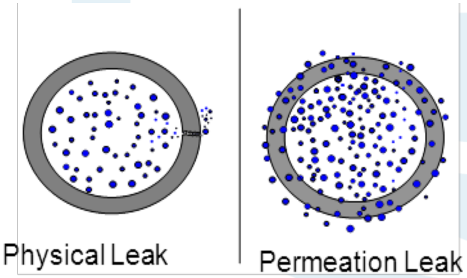
Fiber Reinforced Composite Pipeline Leak Testing





- **NASA Report NSS- 1740.16 Pressure boundary rupture only make up 14 percent of the hydrogen accidents. Accidents due to leakage and improper handling of hydrogen make up a greater percentage of the accidents**

Sample	Leak Rate STD CC H_2/Sec
Fiber 1	9.8×10^{-5}
Poly 1	9.5×10^{-3}
Poly 1+	5.0×10^{-2}

Standard Code Leak Testing Evaluates Leak Rates on the Order of 10^{-2}-10^{-4}cc/sec of the fluid